Materials Science & Engineering A 654 (2016) 169–176

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

The effects of property differences in multiphase sheet steels on local formability

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ARTICLE INFO

Article history:
Received 24 October 2015
Received in revised form
7 December 2015
Accepted 11 December 2015
Available online 14 December 2015

Keywords:
Local formability
Multiphase
Strength ratio
Nanoindentation

ABSTRACT

As the automotive industry continues to push towards higher strength materials, lower weight, and reduced costs, high strength ferrous alloys have provided a viable solution. However, as strength levels increase, formability concerns, specifically in regards to local formability at areas of significant geometrical change, have arisen. One of the contributing factors to reduced formability limits has been identified as localized variations in material microstructure. In contrast to single phase steels used in the past, many of the current alloys currently being pursued utilize complex, multiphase microstructures. This presents new and interesting challenges for the current steel producers and consumers. This paper investigates the influences of systematic differences in phase properties on local formability by use of unique testing techniques including nanoindentation to determine phase hardness, and a bending under tension test to determine formability limits. It was found that increased local formability limits were observed with decreased hardness ratio between the hardest and the softest phase in the microstructure.

1. Introduction

Advanced high strength steels (AHSS) are currently experiencing increased usage in the automotive industry due to their relatively significant improvement in properties and small increase in cost [1]. Common materials include complex phase (CP), dual phase (DP), transformation induced plasticity (TRIP) and twinning induced plasticity (TWIP) steels with tensile strengths in excess of 600 MPa. With higher strengths, smaller thicknesses can be used thereby reducing mass and cost while maintaining vehicle crashworthiness and structural integrity. However, formability has been observed to be a limiting condition in many materials, where failures are observed on cold stamping of these parts at areas of relatively small radii bends. These failures have been termed "shear fractures," as failures occur on alternating 45° planes through thickness, are oriented parallel to the length of the bend, and exhibit minimal localized necking. To date, traditional measures of sheet formability as described on a forming limit diagram (FLD), have been unable to predict specific forming conditions which lead to localized shear fractures [2].

To examine the cause of shear failures, selected studies have investigated the thermal effects of rapid stamping operations of high strength materials, and the subsequent changes in mechanical properties [3]. Others have focused on the importance of microstructure on shear fractures and local formability limits. Analyses based on experimental measurements [4,5] and micromechanical finite element modeling [6,7] have shown that variations in microstructural constituent properties can affect plastic deformation and damage accumulation in high strength multiphase materials. The hardness ratio between microstructural constituents, as quantified via nanoindentation hardness measurements, has been shown to be an important property to assess AHSS formability and to correlate with hole expansion ratios [8] and void formation due to spatially inhomogeneous lattice strains [9]. The current paper extends analyses based on nanoindentation hardness data to systematically evaluate relationships between constituent hardness ratios, microscopic void nucleation mechanisms, and susceptibility to shear fracture in selected laboratory-modified dual phase steels and commercial AHSS.

2. Materials

Two material sets were utilized for the current work. The first set consisted of laboratory processed dual phase steels designed to have a range of martensite volume fractions, distributions, and mechanical properties relevant to current industry. The second set consisted of commercially available AHSS including high strength low alloy (HSLA), DP and TRIP steels. Materials in this set were known to periodically exhibit shear failures in industrial stamping

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http://dx.doi.org/10.1016/j.msea.2015.12.035
0921-5093/

Table 1
Two material sets were used for the current study: (1) laboratory processed dual phase steels, and (2) commercially available AHSS including HSLA, DP and TRIP materials. Martensite volume fractions (MVF) are included for the dual phase steels calculated using ASTM E-562-02.

	Type	Thickness (mm)	MVF (%)	Yield stress	UTS	Uniform strain	C	Mn	Si	Cr	Mo	Al
Material set 1	**AC830**	1.5	36	342	753	0.09	0.1	1.02	0.27	0.01	–	0.05
	AC850	1.5	45	386	785	0.09	0.1	1.02	0.27	0.01	–	0.05
	AC870	1.5	46	613	935	0.03	0.1	1.02	0.27	0.01	–	0.05
	WQ830	1.5	40	372	731	0.14	0.1	1.02	0.27	0.01	–	0.05
	WQ850	1.5	44	375	728	0.11	0.1	1.02	0.27	0.01	–	0.05
	WQ870	1.5	47	530	861	0.05	0.1	1.02	0.27	0.01	–	0.05
Material set 2	**HSLA450**	1.4	–	342	459	0.16	0.1	1.34	0.01	0.04	0	0.05
	DP600	1.0	20.2	360	607	0.14	0.09	1.66	0.01	0.19	0.19	0.06
	DP600	1.4	22.4	420	665	0.13	0.08	1.81	0.01	0.18	0.18	0.04
	TRIP780	1.0	–	385	770	0.13	0.14	2.26	0.07	0.09	0.09	1.84
	DP780	1.0	27	500	854	0.11	0.14	1.95	0.02	0.24	0.17	0.07
	DP980	1.4	49.6	650	1014	0.09	0.15	1.87	0.02	0.17	0.32	0.06

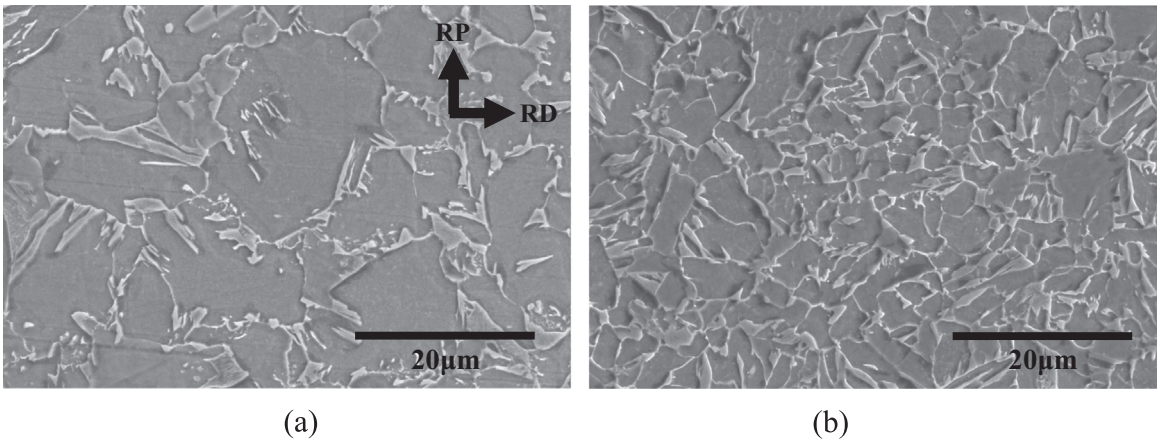

Fig. 1. Secondary electron images of laboratory-processed heat treated microstructures, where the (a) AC830 material and (b) WQ830 material are shown. Ferrite appears dark gray and martensite appears light gray (2 pct nital etch).

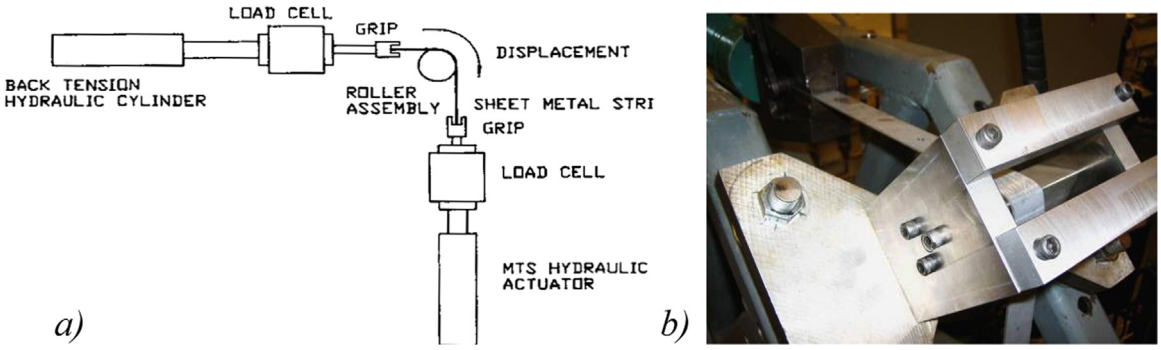

Fig. 2. The bending under tension test, shown by (a) schematic drawing of a commercial test frame, and (b) experimental set up.

trials. Table 1 summarizes the mechanical properties, compositions, and dual phase steel martensite volume fractions as obtained from full characterization studies published previously [4,10].

As shown in Table 1 the two material sets exhibit a range of material properties with dual phase steel martensite volume fractions between 20 and 50 pct, ultimate tensile strengths between 459 and 1014 MPa, and based on multiple different alloying strategies. Steels in Material Set 1 were laboratory-processed to create systematic variations in dual phase steel microstructures in a single alloy system [11]. Prior to intercritical annealing, samples were austenitized in helium at 1000 °C for 30 s after a 240 s heat-up period and either water quenched "WQ" or air cooled "AC". Subsequently, samples were intercritically annealed at either 830 °C, 850 °C, or 870 °C followed by water quenching. The samples are identified by the preconditioning treatment and intercritical temperature (e.g. sample AC830 was air cooled after the austenization heat treating and intercritically annealed at 830 °C). Using this methodology, martensite volume fraction was systematically varied by changes in the intercritical annealing